Recent population changes in freshwater mussels (Bivalvia: Unionidae) and zebra mussels *(Dreissena polymorpha)* in Lake St. Clair, U. S. A.

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Abstract: To determine trends in abundances, we conducted a survey of freshwater mussels (Bivalvia: Unionidae) and zebra mussels (*Dreissena polymorpha* [Pallas,1771]) at five sites in the northwestern portion of Lake St. Clair in 1997. Previous, more extensive spatial surveys between 1986 and 1994 showed that unionids were mostly eliminated from the lake as a result of zebra mussel infestation, but at least a few unionids were still present in the northwestern portion in 1994. The 1994 survey also showed that zebra mussel densities were still increasing in this portion of the lake. In the present survey, no live unionids were collected despite a sampling effort modified from prior surveys specifically to locate live individuals. From these results, we believe that freshwater mussels have been eliminated from the open waters of Lake St. Clair. Zebra mussel populations appear to have reached a steady state in the northwest portion as evidenced by a decrease in mean density from 2,247 m^{-2} in 1994 to 1,237 m^{-2} in 1997, and a decrease in the mean size of individuals in the population. Although they were common in previous surveys, we did not collect any zebra mussels with a shell length > 20 mm.

Key Words: freshwater mussels, unionid extirpation, *Dreissena* infestation, mussel trends, Great Lakes

The introduction and rapid expansion of zebra mussels (*Dreissena polymorpha* [Pallas, 1771]) in North America has led to dramatic ecological changes in aquatic systems where this mussel has become abundant (for overviews on specific systems see Nalepa *et al.*, 1999; Strayer *et al.*, 1999). While most groups of aquatic organisms from bacteria to fish have been affected by the filtering activity and habitat alterations of large *D. polymorpha* populations, the taxonomic group most negatively impacted has been freshwater mussels of the family Unionidae (Bivalvia) (Schloesser *et al.*, 1996; Ricciardi *et al.*, 1998). Zebra mussels attach to the shells of unionids and subsequently impede normal metabolic activities (feeding, respiration, excretion) and burrowing behavior. In addition, large populations of zebra mussels can negatively affect unionids by filtering organic material from the water column thereby reducing amounts of available food (Strayer and Smith, 1996).

We have been documenting population trends of unionids in Lake St. Clair since 1986. In our first survey in that year, we found a diverse unionid community that had changed little since the turn of the century (Nalepa and Gauvin, 1988). Because the lake receives large inputs of high-quality water from Lake Huron and has a rapid flushing rate, habitat conditions tend to favor a diverse and stable fauna (Leach, 1991). Two years after our 1986 survey, the first zebra mussel reported in North America was discovered in the southeastern portion of the lake (Hebert *et al.*, 1989). We subsequently documented abundances of both unionids and *Dreissena polymorpha* in 1990, 1992, and 1994 (Nalepa, 1994; Nalepa *et al.*, 1996). Unionid populations first began to decline in the southeastern portion of the lake and then declined in the northwestern portion. This spatial trend closely paralleled the expansion of the *D. polymorpha* population from the southeast to the northwest over the same time period. In our first survey in 1986, we collected 281 unionids from 29 lakewide sampling sites. This number declined to 248 in 1990, to 99 in 1992, and to six in 1994 (Nalepa *et al.*, 1996). Further, while unionids were found at 25 of 29 sites in 1986, they were collected from only four sites in 1994. All four sites were located in the northwestern region of the lake. Mean densities of *D. polymorpha* in the northwestern portion increased dramatically between 1990 and 1994 (Nalepa *et al.*, 1996).

We present the results of an abbreviated survey of unionid and *Dreissena polymorpha* populations conducted in the northwestern portion of the lake in 1997. The objectives of the survey were to determine whether any unionids

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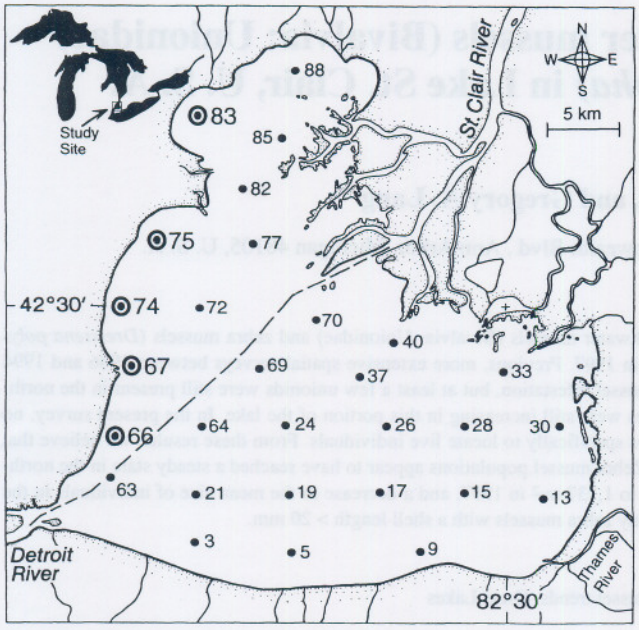

Fig. 1. Location of sampling sites in Lake St. Clair. The circled sites were the sites sampled in 1997 (this study), and all sites were sampled in 1986, 1990, 1992, and 1994. Dashed line represents the shipping channel.

remained in this portion of the lake, and to document density trends in *D. polymorpha* between 1994 and 1997.

METHODS

The sites sampled in 1997 were Stations 66, 67, 74, 75, and 83 (Fig. 1). These sites were located near the western shoreline and were among the last sites to be heavily colonized by zebra mussels. Site designations and locations are the same as those given in Pugsley *et al.* (1985). Details of the sampling protocol are given in Nalepa (1994). Briefly, at each site divers positioned a 0.5 m^2 frame on the bottom and hand-collected all hard material within the frame area to a depth of about 5 cm. Ten replicate samples were taken at each site with divers moving about 2-3 m into the current between replicates. All material collected in a replicate was put into a fine mesh bag, supported within a crate, and then brought to the surface. Substrate material was immediately examined for live unionids. *Dreissena polymorpha* were removed from the substrate (dead unionid shells, rocks, plant material), washed through a 500-um mesh screen, and preserved in 5% formalin.

Using information from our survey in 1994, we knew unionids would be rare in 1997. Therefore, we also surveyed the unionid population using the "diver-transect" method (Isom and Gooch, 1986). At each site, a weighted line 100 m in length was stretched along the bottom, and divers swam on each side of the line searching for unionids. As the divers swam, they slid a measuring rod along the line that extended out from the line 1 m on each side. The area searched for unionids by this method was 200 m^2 per site.

For each of the 10 replicate quadrat samples taken in 1997, up to 500 *Dreissena polymorpha* were counted. Replicates with a greater number of mussels were proportionally split, counted, and the portion applied to the entire sample. Shell lengths of mussels in five of the replicate samples were measured by first placing each cleaned individual onto a clear plastic sheet, and then placing the sheet onto a scanner. The scanning program provided total shell length of each individual. For length-frequency distributions, mussels with a shell length > 5 mm were placed into size categories of 1-mm intervals, while mussels with a shell length < 5 mm were placed into a single size category. In the previous surveys, individuals in all 10 replicates were measured using a digitizer pad.

RESULTS AND DISCUSSION

No live unionids were collected at any of the five sites sampled in 1997 (Fig. 2). While this finding further reinforces our earlier conclusion that unionids have essentially been extirpated from the open waters of the lake (Nalepa *et al.*, 1996), the results are noteworthy because our sampling design was specifically modified to find live animals. In our four earlier surveys, our main objectives were to assess trends in densities, species composition, biomass, and distribution patterns of unionids. The quadrat

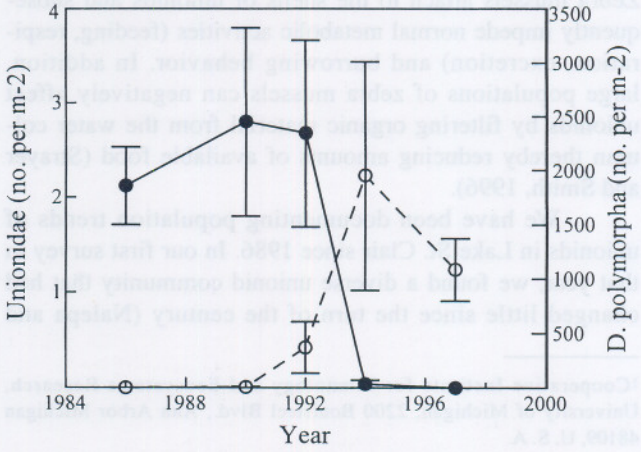

Fig. 2. Mean (± SE) density (no. m^{-2}) of Unionidae and *Dreissena polymorpha* at the five sites sampled in 1997. Densities in 1986, 1990, 1992, 1994 were taken from Nalepa *et al.* (1996). Note that the two taxa have different scales. Unionidae = solid circle, *D. polymorpha* = open circle.

sampling method was employed because it provided the most suitable method to meet these objectives given limited resources (Kovalak *et al.*, 1986). The 29 sites sampled in earlier surveys were systematically located throughout the lake (Fig. 1), and the 10 replicates per site were the minimum needed to provide reliable estimates of population densities (Downing and Downing, 1992). Given the number of sites and replicates, the total area sampled in each of these earlier surveys was only 145 m^2 (10 replicates per site x 0.5 m^2 per replicate x 29 sites). In contrast, the main objective of the 1997 survey was to assess the presence/absence of unionids. Thus, we sampled a much broader area (1,000 m^2 with diver-transect method and 25 m^2 with quadrat method), and limited our efforts to the northwestern portion of the lake where at least some live unionids were found in 1994. We also sampled at sites located nearest to shore where, according to our earlier surveys, densities tended to be greater (Nalepa *et al.*, 1996). Thus, despite a sampling effort purposely designed to find live mussels, none were found. With these findings, it can be stated with some certainty that unionids have been extirpated from the open waters of Lake St. Clair.

Regression models have shown a direct relationship between densities of *Dreissena polymorpha*, the number of *D. polymorpha* attached to unionids, and unionid mortality (Ricciardi *et al.*, 1995). Unionid mortality increases significantly when *D. polymorpha* densities are greater than 1,000 m^{-2}, and extirpation occurs in a few years when mean densities are over 6,000 m^{-2} or 100 per unionid. Further work by Ricciardi *et al.* (1996) showed that mortality can occur with infestations as low as 10 per unionid if attached *Dreissena* are large relative to the unionid. As noted by Nalepa *et al.* (1996), the decline in unionids relative to increased numbers of *D. polymorpha* in Lake St. Clair appeared to fit model predictions very well, but mortality also occurred at some sites where the number of *D. polymorpha* was very low. For instance, unionid densities at Station 83 were 2-4 m^{-2} in 1986, 1990 and 1992. In 1994, unionid density declined to 0 m^{-2} even though the mean density of *D. polymorpha* at this site was only 150 m^{-2}, and the mean number of *D. polymorpha* found attached to unionids was only six. Clearly, *D. polymorpha* can adversely affect unionids in ways other than by direct attachment to the shell. In the Hudson River, unionid populations declined by 59% after *D. polymorpha* became established, although there were few individuals found attached to unionid shells (Strayer and Smith, 1996). It was concluded that the main reason for the unionid decline was a decrease in food availability. In Lake St. Clair, chlorophyll levels declined 2-fold after *D. polymorpha* became abundant (Nalepa *et al.*, 1993), and could have also contributed to the unionid decline.

As found in Lake St. Clair, studies of *Dreissena*-induced mortality in other systems have shown that unionid populations are usually reduced > 90 % within 4-8 years after *D. polymorpha* first becomes established (Ricciardi *et al.*, 1998). The evidence suggests that if zebra mussels are present and able to persist on exposed unionid shells, extirpation of unionids will likely occur over time. On the other hand, other studies have shown that unionids could still be found in certain habitats where *D. polymorpha* attachment is not consistent. For example, some unionids were found in shallow waters (1-2 m) of western Lake Erie despite the presence of *D. polymorpha* and the extirpation of unionids in deeper waters (Schloesser *et al.*, 1997). In these shallow habitats, it was postulated that wave action, water level fluctuations, and winter ice scour either prevented mussels from permanent attachment, or induced zebra mussels to release after initial colonization. In another study, Nichols and Wilcox (1997) found unionids devoid of attached zebra mussels in the soft sediments of a wetland area in western Lake Erie. They noted that unionids in the wetland burrowed into the soft sediments during at least part of the day to avoid high summer temperatures (up to 27°C). It was hypothesized that this burrowing behavior prevented *D. polymorpha* from attaching, or killed any individuals already attached. At this point, it is not clear whether these areas represent permanent unionid refugia, or are merely habitats where extirpation has been delayed. The study in nearshore western Lake Erie was conducted in 1993

Table 1. Mean (±SE) density (no. m^{-2}) of *Dreissena polymorpha* at the five sites in Lake St. Clair that were sampled in 1997. Densities in 1990, 1992, and 1994 were taken from Nalepa *et al.* (1996). Differences between two successive years at each site were tested with the t-test (log +1 transformed). An asterisk indicates density is significantly different ($P < 0.05$) from the density of the previous year.

	Station					
Year	St. 66	St. 67	St. 74	St. 75	St. 83	Mean
1990	0	0	0	0	2	< 1
1992	136 ± 35*	116 ± 20*	389 ± 143*	1466 ± 253*	27 ± 10*	427
1994	6502 ± 504*	3295 ± 1148*	296 ± 58	991 ± 172	150 ± 81	2247
1997	1268 ± 139*	867 ± 163	1874 ± 295*	1992 ± 1086	182 ± 48	1237

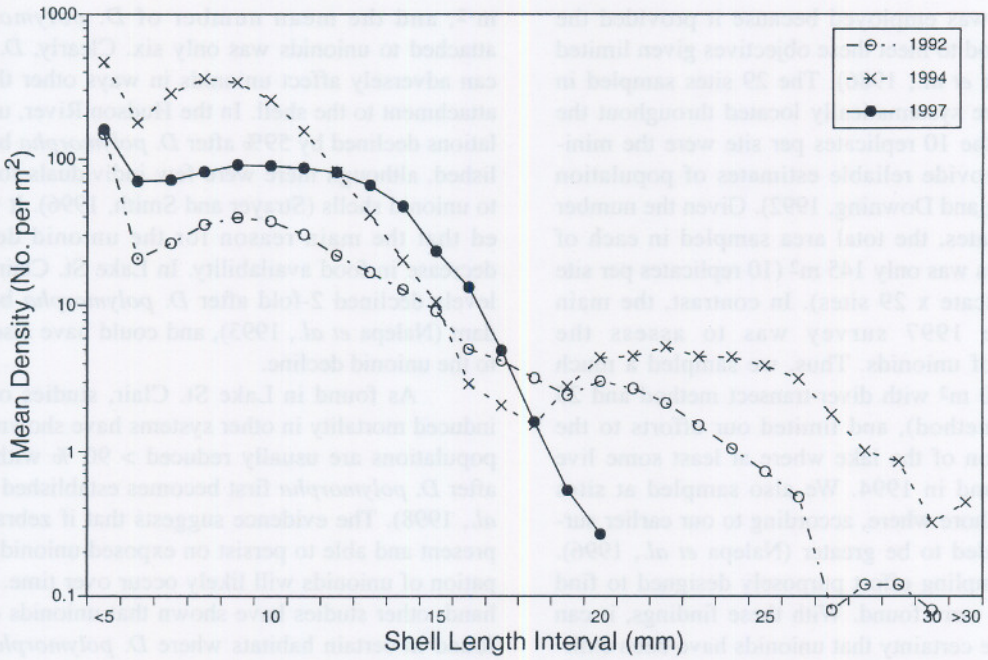

Fig. 3. Size-frequency distribution of *Dreissena polymorpha* in 1992, 1994, and 1997 at each of the five sites sampled in 1997. The scale for the ordinate is logarithmic. 1992 = open, 1994 = hatched, 1997 = solid circle.

(Schloesser *et al.*, 1997), or just five years after *D. polymorpha* became abundant. We still found unionids in Lake St. Clair in 1994, or six years after *D. polymorpha* became abundant, but did not find any unionids three years thereafter. Obviously, follow-up surveys in areas where unionids have been found in the presence of *D. polymorpha* are essential.

Overall, mean densities of *Dreissena polymorpha* at our five sampling sites declined between 1994 and 1997, but there was great variation at individual sites (Table 1, Fig. 2). Densities at the two southernmost sites (Stations 66 and 67) increased between 1992 and 1994 to reach maximum densities, but then declined in 1997. Densities at the three sites located farther north (Stations 74, 75, and 83) were relatively low in 1994, but then increased in 1997. These temporal patterns in abundance are consistent with earlier surveys that showed populations of *D. polymorpha* in Lake St. Clair expanded from southeast to northwest as related to water flow regimes (Nalepa *et al.*, 1996). A high volume of water enters the lake from the St. Clair River, flows through the lake mostly along the shipping channel, and then exits via the Detroit River. This flow pattern impedes zebra mussel larvae in the southeast from easily colonizing the northwest. Based on density trends at individual sites between 1992 and 1997, it would appear that expansion has diminished in the northwestern portion of the lake, and populations are likely approaching an equilibrium with the surrounding environment. Populations reached a similar steady state in the southeastern portion by 1994 (Nalepa *et al.*, 1996). Thus, zebra mussel populations in both the southeastern and northwestern portions of the lake appear to have reached equilibrium within 5-6 years of initial colonization.

A further indication that populations have stabilized in the northwestern portion of the lake is denoted by a decrease in the mean size of individuals in the population (Fig. 3). Generally during the initial years of population expansion, year classes (cohorts) are clearly defined (Griffiths *et al.*, 1991; Nalepa *et al.*, 1995). However, as food resources decline, growth rates slow and older-year classes become indistinct from the younger cohorts. Since metabolic costs increase with size, lower food availability affects large individuals more than small (Walz, 1978 a, b). As a result, overall mean size of individuals within the population declines. Although temporal trends in abundances varied between sites, a clear trend to smaller individuals was apparent (Fig. 3). Yearly size-frequency distributions were significantly different for each of the sites and for all sites combined (G-test; $P < 0.05$). In 1992 and 1994, size-frequency distributions were bimodal (Fig. 3). There was a peak of individuals at 8-11 mm in shell length and another peak at 19-25 mm, which implies a two year life span. By 1997, the modal peak of larger individuals was no longer evident and, in fact, no individuals larger than 20 mm were collected at any of the sites.

In summary, no live unionids were collected in the

open waters of Lake St. Clair despite sampling efforts specifically designed to locate living individuals. Unionids began to decline within two years of when *Dreissena polymorpha* was first recorded in the lake in 1988, and this latest survey tends to confirm that the loss in the open waters is now complete. Future surveys must now focus on surrounding wetland areas that may serve as refugia for surviving populations as found in western Lake Erie. It has been suggested that unionids in such refugia may serve as brood stock to recolonize lake areas if zebra mussel populations ultimately decline (Nichols and Wilcox, 1997). While populations of *D. polymorpha* have now apparently reached a steady-state in Lake St. Clair, future surveys will determine whether populations will decline from present levels and, if so, whether the decline would be sufficient to allow unionids to recolonize.

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